Nearshore Processes

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LONG-TERM GOALS

The long-term goals are to understand the transformation of surface gravity waves propagating across the nearshore to the beach, the corresponding wave-driven circulation, and the associated evolution of surfzone morphology.

OBJECTIVES

The FY00 objectives were to obtain and analyze field observations on natural beaches to develop and test hypotheses about the

- transformation of surface waves across the shoaling region and surf zone
- generation and spatial variation of wave-driven setup and near-bottom circulation
- evolution of the nearshore bathymetry in response to waves and circulation

Additional objectives include providing data supporting other SandyDuck studies of wave transformation, circulation, sediment transport, acoustic properties, and continued development of instrumentation for nearshore observations, including the Nearshore Canyon Experiment (NCEX).

APPROACH

Our approach is to test hypotheses by comparing model predictions with waves, currents, and morphological evolution observed on natural beaches during the Duck94 (North Carolina), SandyDuck (North Carolina), XTREE (southern California), and other field experiments.

WORK COMPLETED

In collaboration with T. Herbers, Boussinesq models for the evolution of directionally spread breaking and nonbreaking waves are being developed and tested by comparison with observations. One-dimensional Boussinesq wave models have been compared with observations made on the cross-shore transect of the Duck94 experiment (Herbers et al. 2000). Also in collaboration with T. Herbers, wavenumbers of shoaling and surfzone waves have been estimated from observations made with the SandyDuck compact arrays of pressure sensors and compared with predictions of a two-dimensional Boussinesq model (Herbers et al. submitted).

Estimates of the bottom drag and terms in alongshore momentum balances have been made from the Duck94 and SandyDuck observations (Feddersen et al. 2000). Wave and current statistics have been used to estimate terms in theories for turbulence-induced bottom drag, and compared with estimates of bottom roughness (Feddersen et al. submitted) and of bottom stress (Trowbridge and Elgar, submitted).

The Duck94 and SandyDuck array observations have been processed to produce estimates of infragravity (A. Sheremet) and shear (student Jim Noyes) waves.

Setup and setdown along the main SandyDuck cross-shore transect have been calculated and compared with theory (Raubenheimer et al. submitted).

The observed evolution of nearshore bathymetry, including the cross-shore location of the sand bar, is being compared with the cross-shore distribution of near-bottom velocity statistics observed during Duck94 (with E. Gallagher, Elgar et al. submitted-a) and SandyDuck (with student Fernanda Hoefel).

Surf zone velocities observed with different types of current meters have been compared with each other and with linear theory (Elgar et al. submitted-b).

RESULTS

Observations and Boussinesq model predictions show that although breaking complicates wave evolution, nonlinear triad interactions are important throughout the shoaling region and the surf zone (Herbers et al. 2000).

Analysis of observations made with compact pressure sensor arrays (SandyDuck) show that nonlinear amplitude dispersion can alter phase speeds by as much as 25% in the frequency range from 2 to 3 times the frequency of the primary spectral peak, consistent with Boussinesq theory (Herbers et al. submitted).

Several nonlinear parameterizations of quadratic bottom stress were shown to be more accurate than linear parameterizations, and to be adequate for many nearshore circulation modeling purposes (Feddersen et al. 2000).

Investigation of bottom stress within and seaward of the surfzone over smooth and rough seafloors suggests that although bedforms affect bottom-generated turbulence and increase the drag coefficient outside the surfzone, breaking-wave-generated turbulence increases the bottom drag coefficient within the surfzone (Feddersen et al. submitted). However, near the outer edge of the surfzone where strong near-bottom currents can smooth seafloor roughness but breaking-wave turbulence does not reach the bottom, the bottom drag coefficient can be lower than in the inner surfzone (Trowbridge and Elgar, submitted).

Observations from collocated acoustic Doppler, acoustic travel time, and electromagnetic current meters deployed in the surfzone near the Scripps pier compare well with each other, demonstrating that acoustic instruments can be used to measure surfzone velocities. These observations also show systematic deviations from linear theory in the relationship between pressure fluctuations and wave-orbital velocities, and between horizontal and vertical velocity fluctuations.

The Duck pier pilings and associated bathymetry produce alongshore gradients in wave height and direction within the SandyDuck array. When incident waves approached the beach obliquely from the south, wave energy observed near the shoreline 200 m downwave of the pier was as much as 50% lower than observed 400 m downwave (Figure 1), and waves close to the pier were more normally incident than farther downwave. A spectral refraction model for waves propagating over the measured bathymetry, which includes a depression under the pier (Figure 1), accurately predicts the observations 400 m downwave of the pier, but overpredicts energy near the pier. Model predictions that include partial absorption of wave energy by the pier pilings reproduce the observed alongshore gradients (Figure 1, inset in upper right corner), suggesting piling-induced dissipation may be important (Elgar et al. 2000).

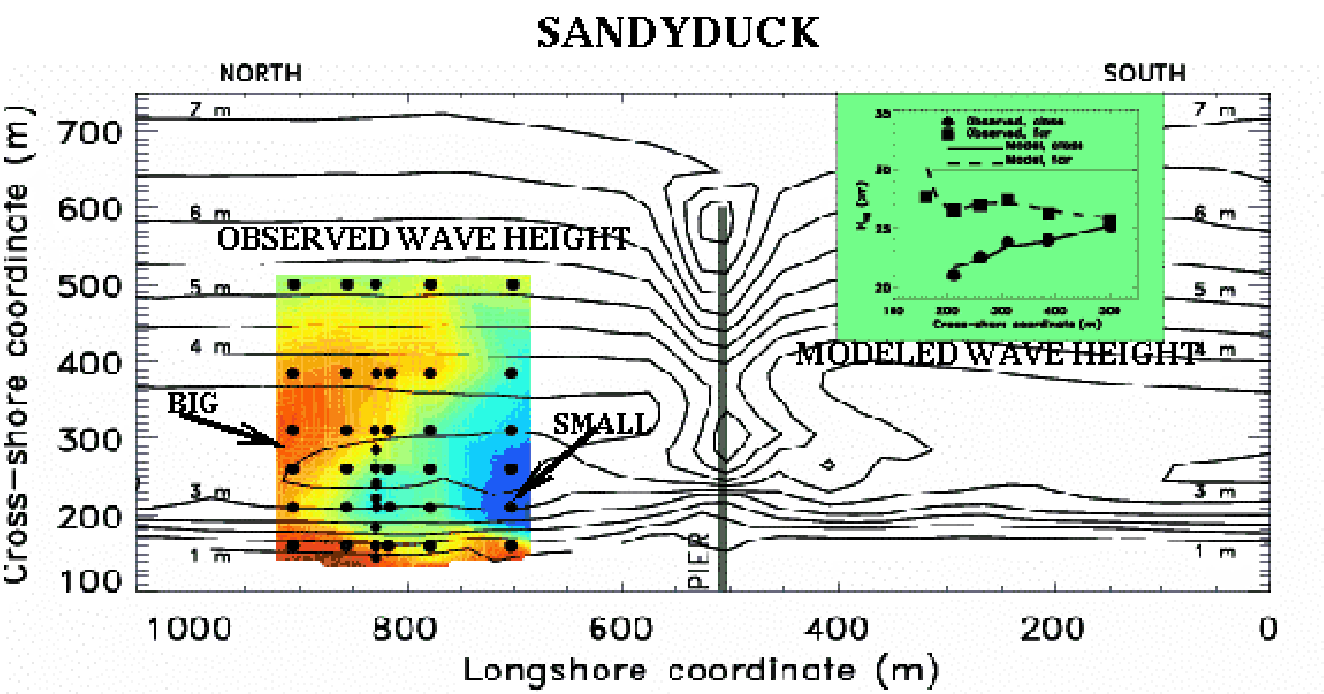

Figure 1: Wave heights during SandyDuck. Color contours show alongshore gradients in wave height (red is big waves, blue is small waves) that were observed with the SandyDuck instrument array filled circles) in August 1997 when 50 cm high waves from the south propagated across the alongshore inhomogeneous bathymetry (contour lines) and past the pier. As shown in the green inset in the upper right, a spectral refraction model that includes dissipation of the waves by the pier pilings predicts accurately the wave heights observed both near the pier (solid curve and filled circles) and 200 m further downwave (dashed curve and filled squares).

During storms, waves break on the sand bar, producing setup (Raubenheimer et al. submitted) and driving a strong offshore-directed near-bottom flow (undertow). The undertow is maximum just onshore of the sandbar crest, and models suggest the corresponding cross-shore gradients in seaward transport of suspended sediment result in offshore migration of the sand bar. As the bar moves offshore, so does the location of wave breaking and maximum undertow. This feedback between waves, circulation, sediment transport and nearshore morphology results in continued offshore migration of the bar until the waves and undertow decrease. Given the initial bathymetry and observed near-bottom currents, the observed offshore bar migration is predicted by an energetics-based sediment transport model (Figure 2).

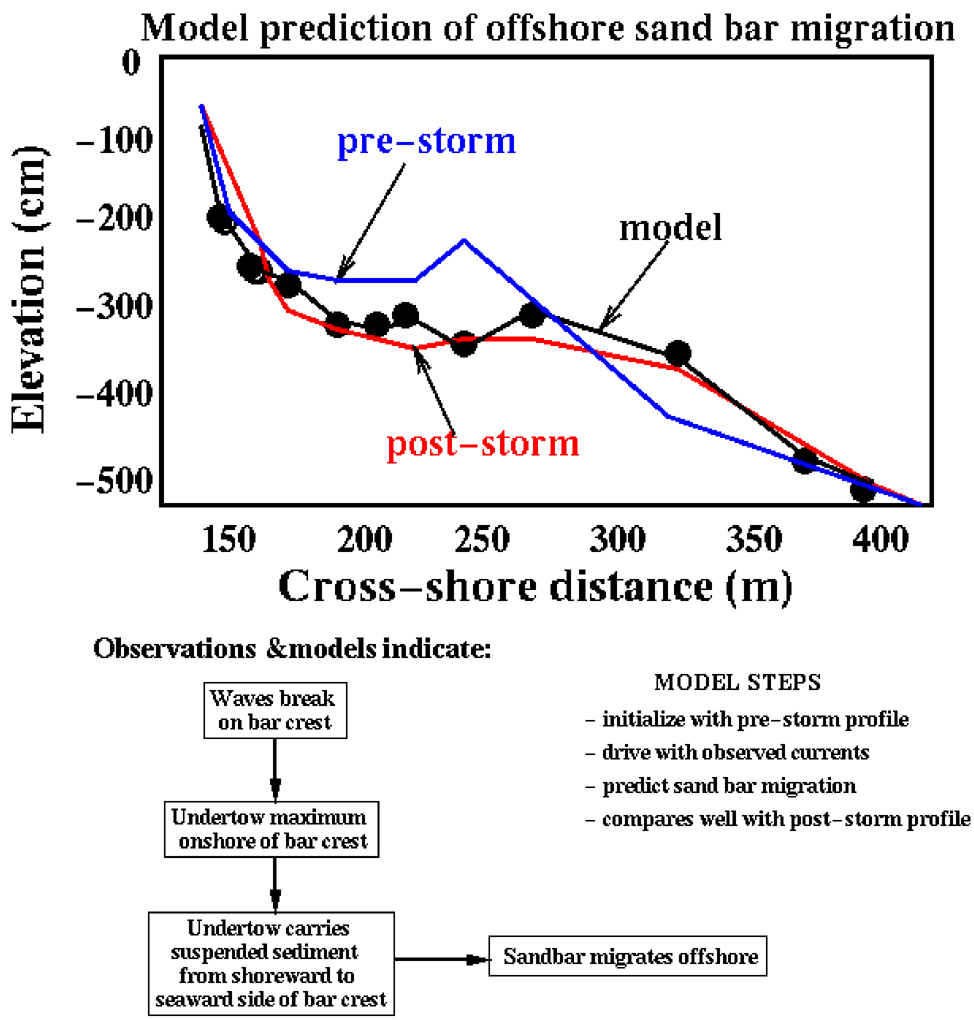

Figure 2: Pre-storm observed depth profile (blue, Time = day 70 in Figure 3), and post-storm observed (red, Time = day 75) and predicted (black) profiles (Gallagher et al. 1998).

In contrast, energetics-based models do not predict the onshore migration of the sand bar observed during less energetic conditions (eg, Figure 3, Time = days 50 - 58). Although velocity skewness was not correlated with the location or migration of the sand bar during Duck4 and SandyDuck, the acceleration skewness, a measure of the difference in the magnitudes of accelerations under the front and rear wave faces, was maximum near the sand bar crest (Figure 3c). The corresponding cross-shore gradients (Figure 3d) of an acceleration-related onshore sediment transport would cause erosion offshore and accretion onshore of the bar crest, consistent with the observed onshore migration of the bar crest. Numerical simulations of waves shoaling over a sand bar show the maximum in acceleration skewness moves onshore with the bar crest, suggesting feedback between waves, wave-orbital velocities, sediment transport, and morphology can result in onshore bar migration when undertow is weak.

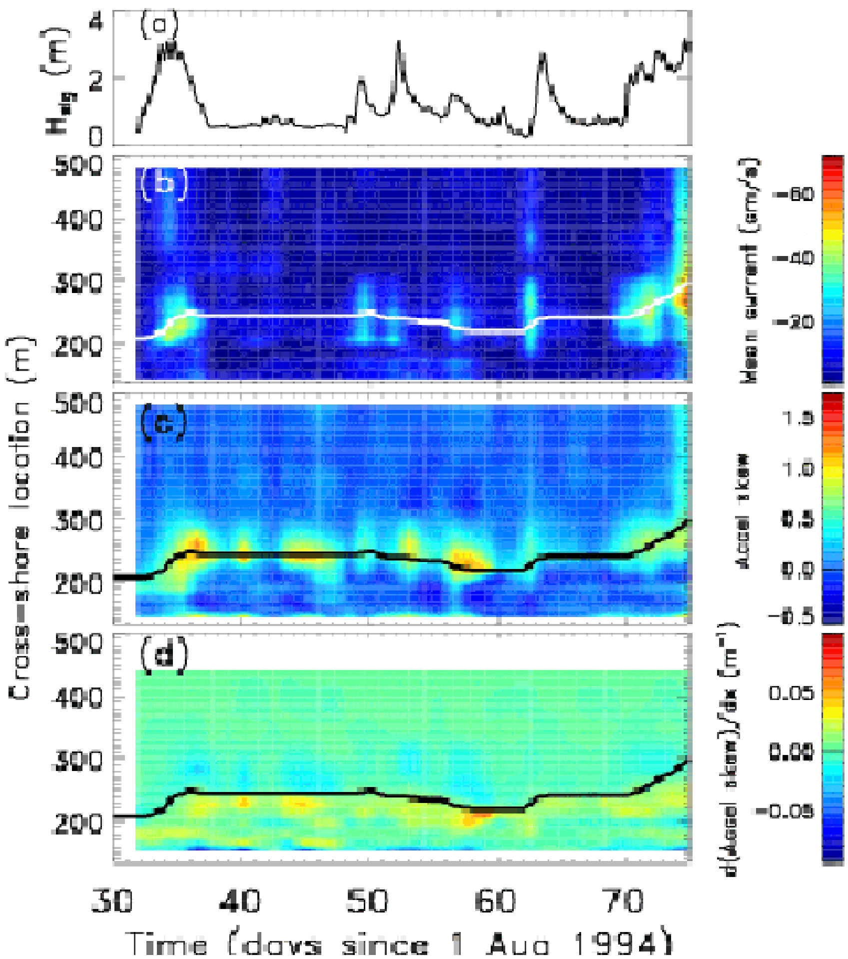

Figure 3: Observed 3-hr mean wave and near-bottom current statistics. (a) Significant wave height observed in 5-m water depth versus time. Contours of (b) mean cross-shore current (negative values are offshore-directed) and (c) skewness of acceleration and (d) cross-shore gradient of the skewness of acceleration of cross-shore orbital velocities as a function of cross-shore location (ordinate) and time (abscissa). The cross-shore location of the sand bar crest is indicated by the solid curve on each contour plot.

The investigations of surfzone waves, currents, and morphology suggest that feedback between waves, circulation, sediment transport, and morphological change leads to offshore sand bar migration during storms when undertow is strong (Figure 4, top), and to onshore migration when mean flows are weak and asymmetrical wave-orbital velocities and accelerations transport sediment shoreward (Figure 4, bottom).

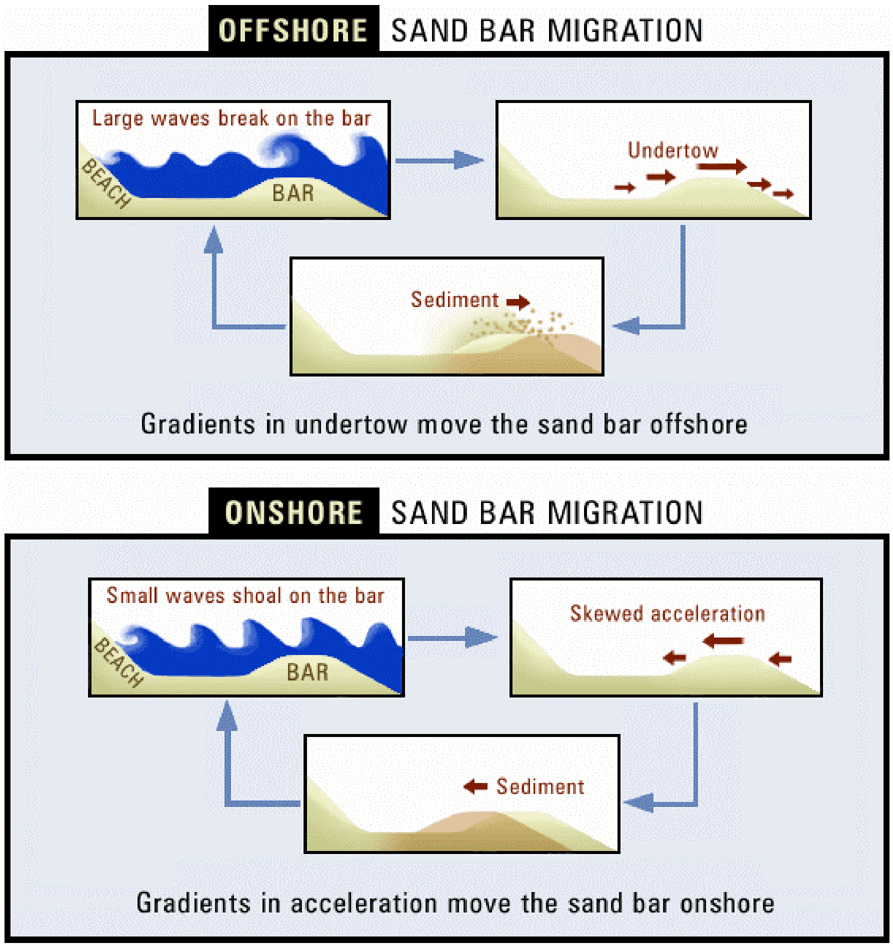

Figure 4: Feedback between waves, circulation, sediment transport, and morphological change that results in undertow-driven offshore bar migration during storms (top), and wave-orbital-velocity-acceleration-driven onshore bar migration when mean flows are weak (bottom).

IMPACT/APPLICATIONS

An application of the field observations is to verify and improve models for nearshore and surfzone waves, circulation, and morphological change. An impact of comparison of model predictions with observations is that near-bottom fluid accelerations may be important for sediment transport and morphological change, and thus should be included in models.

TRANSITIONS

The sonar altimeters developed under this program are being utilized by other scientists, including altimeters mounted on the CRAB (Thornton, Gallagher), on a movable instrument sled (Thornton, Stanton), on the FRF's Sensor Insertion System (Miller, Resio), and as part of the European COAST3D experiments (on the WESP (Gallagher) and on a fixed platform (Miles)).

RELATED PROJECTS

The observations of nearshore waves, currents, and bathymetry are being used to test components of the NOPP nearshore community model (J. Kirby et al.), and to investigate wave propagation across the continental shelf (T. Herber, W. O'Reilly).

The studies of nearshore morphology are in collaboration with an Army Research Office project to investigate onshore sediment transport and sand bar migration.

We also are collaborating with other investigators, including using our measurements of waves, currents, and bathymetry in studies of bottom roughness (hydraulic drag) (Thornton, Drake), wave breaking (Lippmann), the vertical distribution of currents (Thornton, Hathaway), circulation (J. Smith, Kirby, Holland, Svendsen), the determination of bathymetry from wave data (P. Smith, Holland, Kirby), acoustical properties (Hay, Heitmeyer, Means), nearshore bedforms (Hay, Thornton, Gallagher), sediment transport (Miller, Resio), video estimation of surfzone currents (Holland, Holman), swash processes (Holland, Salenger), and turbulence (Trowbridge).

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